

## Advanced Cyclone Combustor with Internal Sulfur, Nitrogen, and Ash Control

### Project completed

### Participant

Coal Tech Corporation

### Additional Team Members

Commonwealth of Pennsylvania, Energy Development Authority—cofunder

Pennsylvania Power and Light Company—supplier of test coals

Tampella Power Corporation—host

### Location

Williamsport, Lycoming County, PA (Tampella Power Corporation's boiler manufacturing plant)

### Technology

Coal Tech's advanced, air-cooled, slagging combustor

### Plant Capacity/Production

23 x 10<sup>6</sup> Btu/hr of steam

### Coal

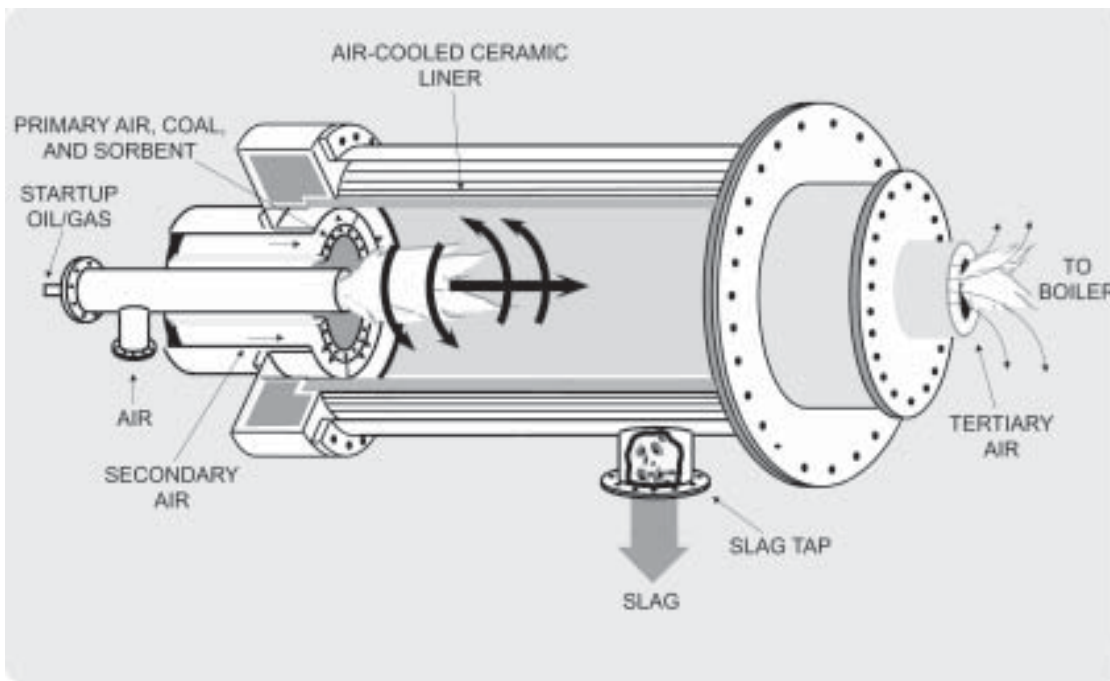
Pennsylvania bituminous, 1.0–3.3% sulfur

### Project Funding

Total project cost	\$984,394	100%
DOE	490,149	50
Participant	494,245	50

### Project Objective

To demonstrate that an advanced cyclone combustor can be retrofitted to an industrial boiler and that it can simultaneously remove up to 90% of the SO<sub>2</sub> and 90–95% of the ash within the combustor and reduce NO<sub>x</sub> to 100 ppm.

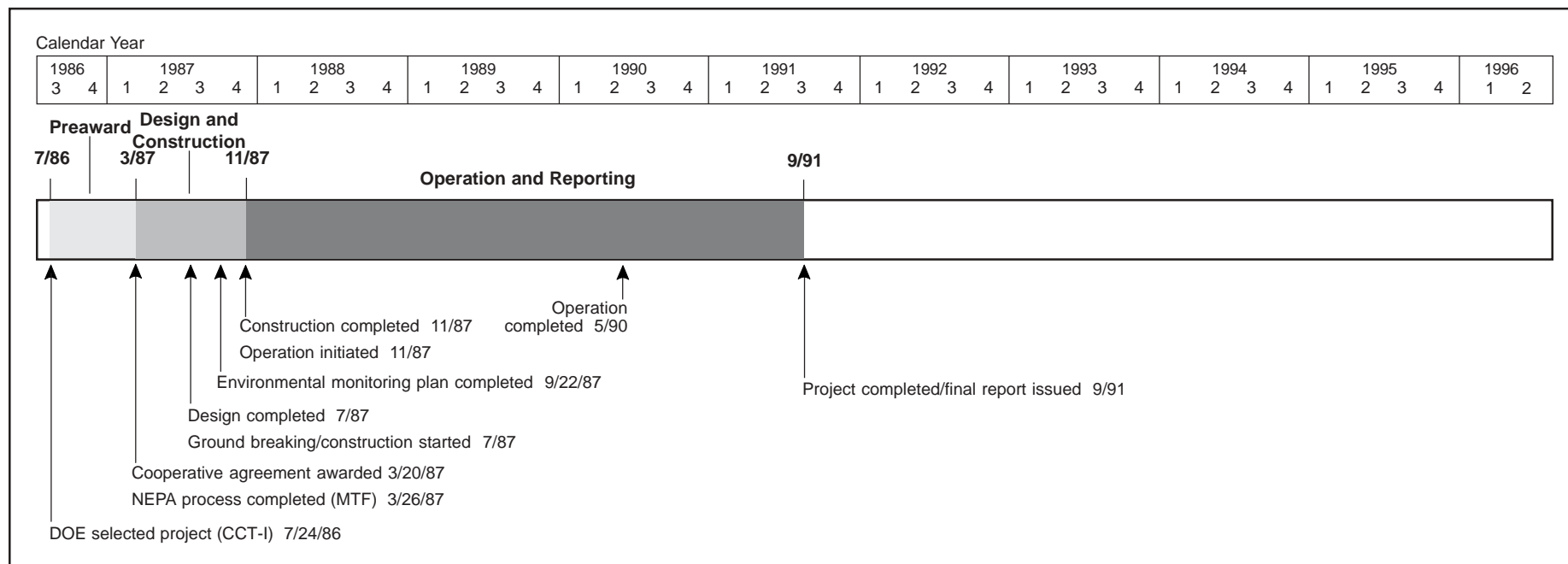


### Technology/Project Description

Coal Tech's horizontal cyclone combustor is lined with an air-cooled ceramic. Pulverized coal, air, and sorbent are injected tangentially toward the wall through tubes in the annular region of the combustor to cause cyclonic action. In this manner, coal-particle combustion takes place in a swirling flame in a region favorable to particle retention in the combustor. Secondary air is used to adjust the overall combustor stoichiometry. Tertiary air is injected at the combustor/boiler interface. The ceramic liner is cooled by the secondary air and maintained at a temperature high enough to keep the slag in a liquid, free-flowing state. The secondary air is preheated by the combustor walls to attain efficient combustion of the coal particles in the fuel-rich combustor. Fine coal pulverization allows combustion of most of the coal particles near the cyclone wall. The combustor was designed so that a high percent-

age of the ash and sorbent fed to the combustor is retained as slag. For NO<sub>x</sub> control, the combustor is operated fuel rich, with final combustion taking place in the boiler furnace to which the combustor is attached. The SO<sub>2</sub> is captured by injection of limestone into the combustor. The cyclonic action inside the combustor forces the coal ash and sorbent to the walls where it can be collected as liquid slag. Under optimal operating conditions, the slag contains a significant fraction of vitrified coal sulfur. Downstream sorbent injection into the boiler provides additional sulfur removal capacity.

In Coal Tech's demonstration, an advanced, air-cooled cyclone coal combustor was retrofitted to a 23 x 10<sup>6</sup> Btu/hr, oil-fired package boiler located at the Tampella Power Corporation boiler factory in Williamsport, Pennsylvania.



## Results Summary

### Environmental

- SO<sub>2</sub> removal efficiencies of over 80% were achieved with sorbent injection in the furnace at various calcium-to-sulfur (Ca/S) molar ratios.
- SO<sub>2</sub> removal efficiencies up to 58% were achieved with sorbent injection in the combustor at a Ca/S molar ratio of 2.0.
- A maximum of one-third of the coal's sulfur was retained in the dry ash removed from the combustor (as slag) and furnace hearth.
- At most, 11% of the coal's sulfur was retained in the slag rejected through the combustor's slag tap.
- NO<sub>x</sub> emissions were reduced to 184 ppm by the combustor and furnace, and to 160 ppm with the addition of a wet particulate scrubber.
- Combustor slag was essentially inert.
- Ash/sorbent retention in the combustor as slag averaged 72% and ranged from 55–90%. Under more fuel-lean conditions, retention averaged 80%.

- Meeting local particulate emissions standards required the addition of a wet venturi scrubber.

### Operational

- Combustion efficiencies of over 99% were achieved.
- A 3-to-1 combustor turndown capability was demonstrated. Protection of combustor refractory with slag was shown to be possible.
- A computer-controlled system for automatic combustor operation was developed and demonstrated.

### Economic

- Because the technology failed to meet commercialization criteria, economics were not developed during the demonstration. However, subsequent efforts indicate that the incremental capital cost for installing the coal combustor in lieu of oil or gas systems is \$100–200/kW.

## Project Summary

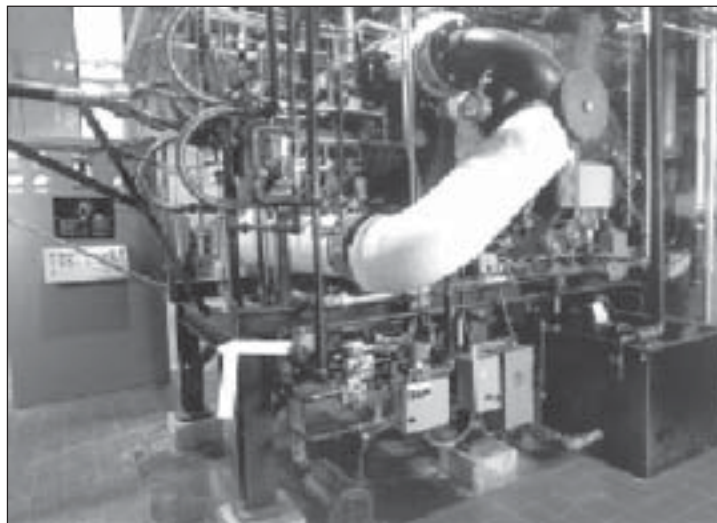
The novel features of Coal Tech's patented ceramic-lined, slagging cyclone combustor included its air-cooled walls and environmental control of  $\text{NO}_x$ ,  $\text{SO}_2$ , and solid waste emissions. Air cooling took place in a very compact combustor, which could be retrofitted to a wide range of industrial and utility boiler designs without disturbing the boiler's water-steam circuit. In this technology,  $\text{NO}_x$  reduction was achieved by staged combustion, and  $\text{SO}_2$  was captured by injection of limestone into the combustor and/or boiler. Critical to combustor performance was removal of ash as slag, which would otherwise erode boiler tubes. This was particularly important in oil furnace retrofits where tube spacing is tight (made possible by the low-ash content of oil-based fuels).

The test effort consisted of 800 hours of operation, including five individual tests, each of four days duration. An additional 100 hours of testing was performed as part of a separate ash vitrification test. Test results obtained during operation of the combustor indicated that Coal Tech attained most of the objectives contained in the cooperative agreement. About eight different Pennsylvania bituminous coals with sulfur contents ranging from 1.0–3.3% and volatile matter contents ranging from 19–37% were tested.

### Environmental Performance

A maximum of over 80%  $\text{SO}_2$  reduction measured at the boiler outlet stack was achieved using sorbent injection in the furnace at various Ca/S molar ratios. A maximum  $\text{SO}_2$  reduction of 58% was measured at the stack with limestone injection into the combustor at a Ca/S molar ratio of 2. A maximum of one-third of the coal's sulfur was retained in the dry ash removed from the combustor and furnace hearths, and as much as 11% of the coal's sulfur was retained in the slag rejected through the slag tap. Additional sulfur retention in the slag is possible by increasing the slag flow rate and further improving fuel-rich combustion and sorbent-gas mixing.

With fuel-rich operation of the combustor, a three-fourths reduction in measured boiler outlet stack  $\text{NO}_x$  was ob-



The slagging combustor, associated piping, and control panel for Coal Tech's advanced ceramic-lined slagging combustor are shown.

tained, corresponding to 184 ppm. An additional reduction was obtained by the action of the wet particulate scrubber, resulting in atmospheric  $\text{NO}_x$  emissions as low as 160 ppm.

All the slag removed from the combustor produced trace metal leachates well below EPA's Drinking Water Standard. Total ash/sorbent retention as slag in the combustor, under efficient combustion operating conditions, averaged 72% and ranged from 55–90%. Under more fuel-lean conditions, the slag retention averaged 80%. After the CCT project, tests on fly ash vitrification in the combustor, modifications to the solids injection system, and increases in the slag flow rate produced substantial increases in the slag retention rate. To meet local stack particulate emission standards, a wet venturi particulate scrubber was installed at the boiler outlet.

### Operational Performance

Combustion efficiencies exceeded 99% after proper operating procedures were achieved. Combustor turndown to  $6 \times 10^6$  Btu/hr from a peak of  $19 \times 10^6$  Btu/hr (or a 3-to-1 turndown) was achieved. The maximum heat input during the tests was around  $20 \times 10^6$  Btu/hr, even though the combustor was designed for  $30 \times 10^6$  Btu/hr and the

boiler was thermally rated at around  $25 \times 10^6$  Btu/hr. This situation resulted from facility limits on water availability for the boiler. In fact, due to the lack of sufficient water cooling, even  $20 \times 10^6$  Btu/hr was borderline, so that most of the testing was conducted at lower rates.

Different sections of the combustor had different materials requirements. Suitable materials for each section were identified. Also, the test effort showed that operational procedures were closely coupled with materials durability. As an example, by implementing certain procedures, such as changing the combustor wall temperature, it was possible to replenish the combustor refractory wall thickness with slag produced during combustion rather than by adding ceramic to the combustor walls.

The combustor's total operating time during the life of the CCT project was about 900 hours. This included approximately 100 hours of operation in two other fly ash vitrification test projects. Of the total time, about one-third was with coal; about 125 tons of coal were consumed.

Developing proper combustor operating procedures was also a project objective. Not only were procedures for operating an air-cooled combustor developed, but the entire operating database was incorporated into a computer-controlled system for automatic combustor operation.

### Commercial Applications

The goal of this project was to validate the performance of the air-cooled combustor at a commercial scale. While the combustor was not yet fully ready for sale with commercial guarantees, it was believed to have commercial potential. Subsequent work was undertaken, which has brought the technology close to commercial introduction.

### Contacts

Bert Zauderer, President, (610) 667-0442

Coal Tech Corporation

P.O. Box 154

Merion Station, PA 19066

coaltechbz@compuserve.com

(610) 677-0576 (fax)

William E. Fernald, DOE/HQ, (301) 903-9448

James U. Watts, NETL, (412) 386-5991

## References

*The Coal Tech Advanced Cyclone Combustor Demonstration Project—A DOE Assessment.* Report No. DOE/PC/79799-T1. U.S. Department of Energy. May 1993. (Available from NTIS as DE93017043.)

*The Demonstration of an Advanced Cyclone Coal Combustor, with Internal Sulfur, Nitrogen, and Ash Control for the Conversion of a 23-MMBtu/Hour Oil Fired Boiler to Pulverized Coal; Vol. 1: Final Technical Report; Vol. 2: Appendixes I–V; Vol. 3: Appendix VI.* Coal Tech Corporation. August 1991. (Available from NTIS as DE92002587 and DE92002588.)

*Comprehensive Report to Congress on the Clean Coal Technology Program: Advanced Cyclone Combustor with Internal Sulfur, Nitrogen, and Ash Control.* Coal Tech Corporation. Report No. DOE/FE-0077. U.S. Department of Energy. February 1987. (Available from NTIS as DE87005804.)



Coal Tech's slagging combustor demonstrated the capability to retain, as slag, a high percentage of the non-fuel components injected into the combustor. The slag, shown on the conveyor, is essentially an inert, glassy by-product with value in the construction industry as an aggregate and in the manufacture of abrasives.